Technion — Israel Institute of Technology
Department of Physics
Infrared Radiometry Laboratory

EMISSION AND TRANSMISSION OF ATMOSPHERIC RADIATION AND THEIR INFLUENCE ON THE PERFORMANCE OF ELECTRO-OPTICS SYSTEMS - MEASUREMENTS, ANALYSIS AND MODELLING: FINAL REPORT

by

Ami Ben-Shalom

September 1983

European Research Office US Army

London, England

Contract No. DAJA 37-81-C-0504

Technion R & D Foundation, Haifa, Israel

Report No. R.A.A. / 83-59

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A137 359	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Emission and Transmission of Atmospheric Radiation and Their Influence on the Performance of Electro-Optics Systems - Measurement, Analysis and Modelling.		5. TYPE OF REPORT & PERIOD COVERED Final Technical Jun 82 - Mar 83
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ami Ben-Shalom		8. CONTRACT OR GRANT NUMBER(s) DAJA37-81-C-0504
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics, Technion R&D Foundation, Haifa, Israel		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102A-1T161102-BH57-01
11. CONTROLLING OFFICE NAME AND ADDRESS USARDSG-UK Box 65, FPO NY 09510		12. REPORT DATE Sept 83
		13. NUMBER OF PAGES 67
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approvied for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric transmission; visible wavelengths; infrared; transmittance; extinction.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements were made at visible, infrared (IR) and near millimeter wave (NMMW) wavelengths to determine the effect of various atmospheric conditions including those containing artificially generated dust, on transmission. Results from these tests indicate little or no attenuation at NMMW frequencies (96 GHz, 140 GHz, 220 GHz), while there were appreciable transmittance losses at visible (0.4 - 1.1 um) and IR (3.0 - 5.5 um, 8.0 - 13.0 um) wavelengths. Analysis of the visible and IR transmittance data obtained through vehicle -generated dust clouds indicated a spectral dependency after the fallout of and

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20. (contd) the heavier particles. Extinction coefficients were calculated for each of the bandwidths. The ratio between the IR, NMMW, and visible wavelengths were 0.86 for 3.0 - 5.5 um, 0.78 for 8.0 - 13.0 um, and less than 0.003 for 96 GHz, 140 GHz and 220 GHz.

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1. Introduction

The objectives of this contract were to measure atmospheric transmittance of electromagnetic radiation, within selected narrow wavelength bands, within the general wavelength band of visible (0.4-0.7 micron), near infrared (3-5 micron) and far infrared (8-12 micron). These measurements will be made under a wide variety of atmospheric conditions and over a number of ranges. Specific field tests will be selected in coordination with technical personnel of the US Army Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico.

The contractor, Technion R & D Foundation, shall designate Dr. Ami Ben-Shalom from Infrared Radiometry Laboratory, Physics Dept., Technion, as the principal investigator, who shall be continuously responsible for the conduct of the contract at US Army ASL, W.S.M.R. New Mexico, U.S.A. Effective date of the contract - 81. Jul. 21; end at 83. Jul. 21.

Six Interim reports had been delivered during the 24 months of this contract, and they are part of this final report.

2. Description of the Contract-LOVIR Objectives

After coordination with Dr. D. Snider, Chief of Electro-Optics Environments Branch, U.S. Army Atmospheric Sciences Laboratory, it was agreed that the work will be focused at Mr. Joseph Butterfield group - LOVIR, Low Visibility Infrared Measurements Group. After several weeks of learning and becoming familiar with this group, a general work plan was proposed, that included the following points:

a. The basic measuring instrumentation of relative transmittance, that was received from NV/EOL: 4 Barnes transmissometers and 2 Vis/IR sources, need

to be prepared for a reliable transmittance field measurements.

b. Integration and testing of a new digital acquisition system, for accumulate the measured data and present "first look" results in the field site.

c. To enhance the instrumentation and procedures of LOVIR.

d. To take part in a set of data collection exercises in the field with the LOVIR group.

e. To reduce and analize the LOVIR data as comparisons to the laboratory measurements previously made and as a test of EOSAEL *propagation* models.

3. LOVIR - ASL Experimental Facility

Infrared-Optical devices incorporated into modern weapon systems are strongly influenced by the dirty atmosphere and battlefield environement. The U.S. Army is very interested in conditions, where the visibility becomes limited (5 km or less) by man-made obscuration (smoke, fire products, WP) or by natural obscuration like dust, fog, haze, rain and snow and their influence) on these devices.

Field tests are required for the determination of the quantitative effects of these obscurations on various E-O sensors and weapon systems. However, to run a field test for each system (or a prototype in the R & D stage) under different atmospheric conditions and obscurations is impractical uneconomical and impossible at all. Therefore there is a need to develop physical and optical models, that will simulate the phenomena of the actual field reality.

A.S.L. has recently developed such a model - "EOSAEL-82, The Electro-Optical Systems Atmospheric Effects Library" - which is composed of sets of programs that help the user in wide range of problems that are related to the performance of E-O systems such as: contrast effects; laser beam jitter and wander; laser

back-scatter; atmospheric transmission through the natural environment, smokes fogs, and dirt/dust munition expenditures; probability of detection for static targets; transmittance through self-screening grenades and climatological conditions for certain selected European and Middle East locations, which affect the optical properties of the atmosphere. These calculations can be done at broadband or narrowband spectral regions in the visible and the IR up to near millimeter wavelengths (0.4 m - 300 GHz), as well as at laser frequencies.

The EOSAEL-82 is based on experimental data from a limited number of field tests and on empirical models. In all these tests, the extinction coefficients of a 3-D obscuration cloud, in the visible and Infrared, was obtained from only one optical path.

To compare the 3-D results of the EOSAEL-82 predictions to the results of field measurement, we have to measure simultaneously the obscuration at different optical paths through the 3-D volume of the cloud.

LOVIR Facility

The IR equipment used today for measurement of low visibility conditions at the Atmospheric Sciences Laboratory of the US Army is based on Barnes transmissometers. The transmissometer system is composed of a source and receivers. The source is a 4.7" off-axis paraboloid which collimates simultaneously the visible beam (from halogen-tungsten 150 W lamp) and the I.R. beam (from 1000°C Black-Body source) over the optical path to the receivers. Both beams are chopped at 1000 Hz (approximately).

The receivers (4" and 8" collecting aperture) are based on the classical optics of a Cassegrain configuration, which is combined with two optical relay

systems, filters and detectors. This equipment is operated by a group of 3 man with very good experience in field work, but they need more manpower with experience in optics and computers, to be able to improve the measurement set-up capability.

The basic set-up from NVEOL, was able to conducted only one optical path at visible, 3-5 and 8-12 micron. The first goal was to improve the measurement set-up of LOVIR capability for:

1. 3 separate optical paths;
2. Data acquisition of atmospheric Transmission;
3. Narrowband, Wideband and Spectral response at the 0.4-0.7 µm and 2.5-14.5 µm spectral regions;
4. Data acquisition at optical paths up to 3 km range;
5. Real time (at field) data processing and presentation.

As is shown in Fig. 1, the ASL Atmospheric Transmission Measurement Set-Up will be based on 3 independent sets (A, B and C) of transmissometers, V.H.F. sync. system, digital data acquisition, processing and printing system with backup of analog recording equipment.

The ASL visible and I.R. sources set-up will be based on 3 units of modified 4" BARNES systems, two units exist, one more will be ordered in the future (Fig. 2).

The ASL visible and I.R. Receivers set-up will be based on 3 different sets (as shown in Fig. 3).

Set A for short range, will be based on two 4" Barnes receivers with Insb and CMT Cooled detectors, and 3" visible telescope with Si detector.

Set B for long range, will be based on 2 modified 8" Barnes Mark II Radiometers, one with two-color InSb/CMT detector for I.R., and the second with Si detector. Both will have C.V. F's for wavelength discrimination. This set will include also a 8" telescope with Si detector for photopic detection.

Set C is a new design multispectral radiometer that AFWAL is constructing for ASL, with 8" neutonian optics. A dichro-ic mirror splits the visible part of the spectrum to a Si detector in one channel, and the IR part of the spectrum to the second channel which will have a CVF and two-color cooled detector.

The start state of the experimental set-up is that all the 3 sets of receivers have to be modified and new components have to be added to them. The goal is to bring this set up to full completion and operating conditions at the end of 1983. This will allow to conduct simultaneously 3 separate measurements at 3 different optical paths through the 3-D obscuration cloud. A schematic diagram is shown in Fig. 4. The data acquisition system is expected to yield the results (processed input data and experimental results) a short time after the field test in the test site.

In SNOW ONE A test, Dec. 1981 - Feb. 1982, a digital data collecting and processing unit was used for digitizing the analog outputs, formatted and stored on a digital cassette.

In BICT III test, May 1982, the new AFWAL receiver, and one 3.5" D. Questar were used for collecting visible and IR radiation over LOS of 2 km.

In Nov. 1982, Set A (recievers) was compiled and prepared for use in Vertical Structure test in England, and 8" two channel (0.4-0.7 and 1.06 micron) Questor

assembled for the RAIN ASL-HDL test in Jan. 1983.

Finally, the following LOVIR experimental facility for transmittance is now available:

1. Radiation sources (visible and infrared):

   a) 4.8" D. modified Barnes

   b) 4.8" D. modified Barnes.

   c) 8" D. home made.

2. Radiation receivers (visible and infrared):

Set A: (Small and mobile, one unit)	a) 1.06 μm, 3.5" D. Questar
	b) 0.4-0.7 μm, photopic 3.5" C.
	c) 3-5 μm, 4" D. Barnes
	d) 8-12 μm, 4" D. Barnes.
Set B (Large optics, three units)	a) 0.4-1.1 μm, 8" D. Barnes
	b) 0.4-0.7, 1.06 μm, 8" D.
	c) 8-12 μm, 8" D. Barnes.
Set C: (Large optic, one unit)	a) AFWPL 8": 0.4-1.1 μm
	Three color 3-5 μm
	8-12 μm.

For more technical detail see appendix A.

4. Field Tests Data Collection Exercises

The principal investigator of this contract, together with the LOVIR group, using the LOVIR set-up, plan and conduct the following data collection exercises in the field:

a) SNOW ONE A - Dec. 1981 - Feb. 1982, Vermont.

b) BICT-III - May-June 1982, New Mexico.

c) RAIN A - July 1982, Virginia.

d) RAIN B - Jan. 1983, Oregon

Data reduction was also made for the test mentioned above and SNOW ONE B (Dec. 1982). For information on data reported see references.

5. ASL/HDL RAIN B Test

Data on the behaviour of visible, infrared and near millimeter waves under arious meteorological conditions can be found in literature. Because these data are gathered on difficult to describe correctly (especially fog, rain, snow conditions) there is a need for comparison of the behaviour of near millimeter, infrared and visible waves under the same meteorological conditions. To be able to compare, simultaneous measurements had been made along nearby paths of 1 km, during tests RAIN A and RAIN B by ASL and HDL. In Jan. 1982, Astoria Oragon, attenuation measurements were carried out simultaneously by ASL (LOVIR, TACS) and HDL (NMMW).

More than 162 hours of rain data (Drizzle, widespread) were collected and reduced.

The attenuation data in visible and infrared is now reduced and analized,

together with particle (rain, fog) and meteorological data. Preliminary results show that extinction coefficient relationships with rainfall intensities are close to those given by R. Reiter (Germany - DAJA37-80-C-0345, 1982) and not those used in EOSAEL-82. Final data report of these rain tests will be published in several months from now.

6. Recommendations

6.1 Instrumentation and Measurements

The main objective to enhance the LOVIR facility was successfully achieved. Today LOVIR is able to conduct data collection in 3 separated LOS, on three different sides, simultaneously. But in the long term, the need for more reliable data with more information and details request smart sensors and receivers. The main limitation today is the small F.O.V. of the receivers. The need for F.O.V. of 2-4 mrad is when long path, of more than 10 km, is requested. But the upper limit for LOVIR is about 3 km, therefore sensors with flat and wide F.O.V. (about 1°, ~17 mrad) will improve the field operation in long time measurements.

The second recommendation is to add more equipment for Real time data processing and presentation (computer, plotters, etc.), to decrease the time between the test and the final data report.

Also purchasing of E-O general instruments and components for further improvement of the experimental set-up of the field laboratory must go on.

There is a need for a data link between the source side and the receiver side, and a small 4 channel telemetry system can be suitable.

6.2 Data Reduction and Analysis

The only objective of the LOVIR group at the side is to provide reliable data on digital tape. The amount of experience powerman (2 men per one set of LOVIR is minimum) in field measurements must be suitable to the mission of LOVIR group. For near real time data reduction and presentation there is a need for a separate group in the field (2-3 men) that will reduce the data on a separate computer and present "Final-look" data at the site. In the last year, this part received the main support from the new chief (Mr. D. Faioni) of measurements and analysis branch and PSL contractors and must be continued.

Fig 1. ASL ATMOSPHERIC TRANSMISSION/RADIATION MEASUREMENT SETUP

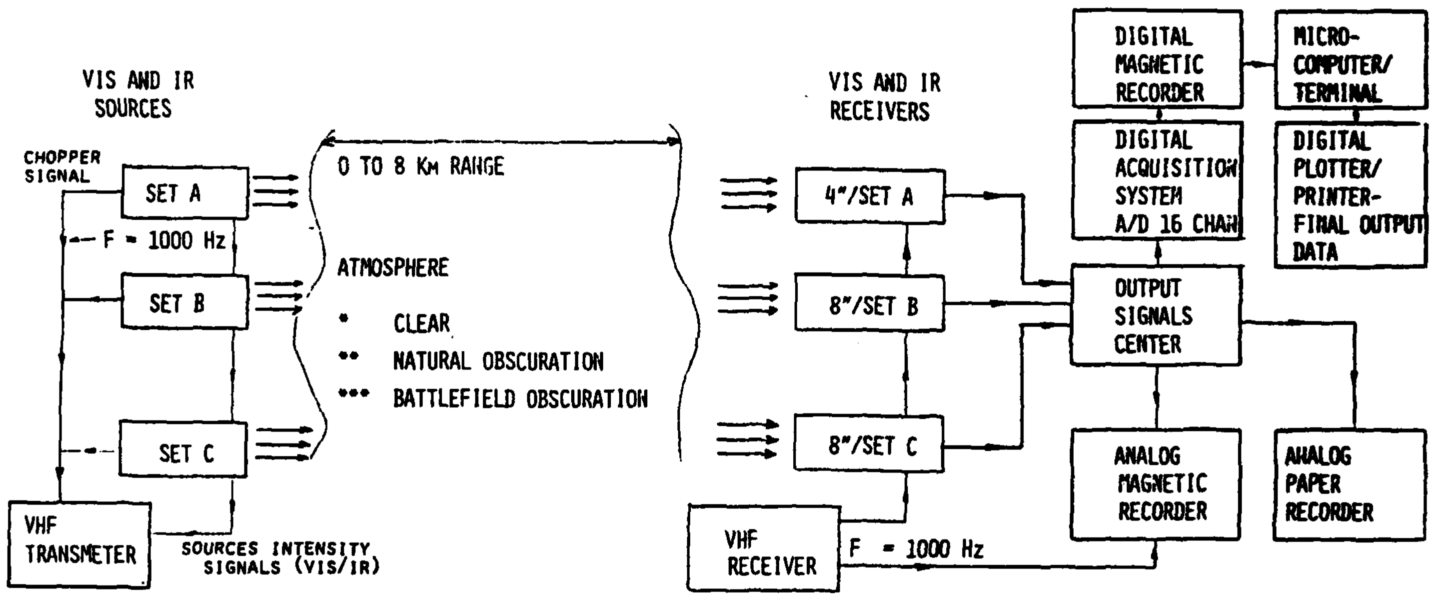
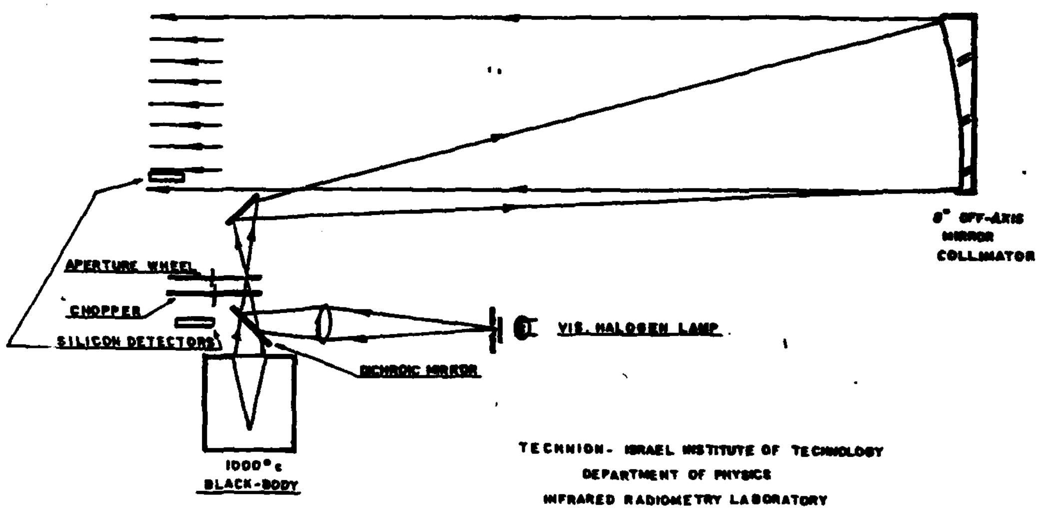


FIG. 2


8" OFF-AXIS
MIRROR
COLLIMATOR
APERTURE WHEEL
CHOPPER
SILICON DETECTORS
VIS. HALOGEN LAMP
DICHROIC MIRROR
1000°c
BLACK-BODY
TECHNION- ISRAEL INSTITUTE OF TECHNOLOGY
DEPARTMENT OF PHYSICS
INFRARED RADIOMETRY LABORATORY

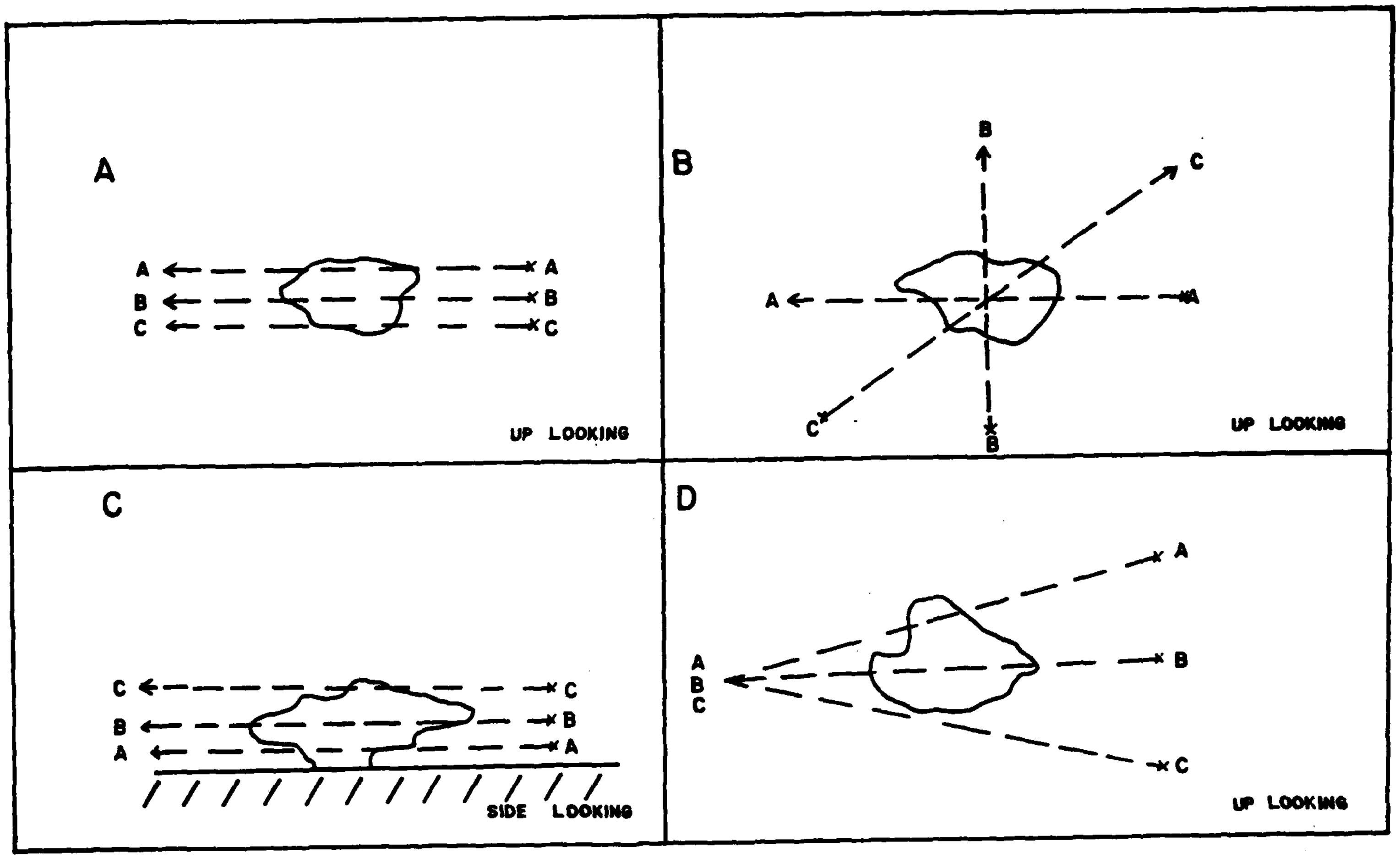


Fig. 4 Source - Receiver Geometry for Three Separate Optical Paths

Fig. 3. ASL VISIBLE AND INFRARED RECEIVERS SETUP

SET	TYPE	INSTRUMENT	SPECTRAL REGION (μm)	DETECTOR	TYPE OF FILTERS
A 4"	TRANSMISSOMETER	4" BARNES	3.0-5.5	InSb	NARROW BANDS WIDE BANDS
	TRANSMISSOMETER	4" BARNES	8.0-13.0	CMT	NARROW BANDS WIDE BAND
	TRANSMISSOMETER*	3" QUESTAR	0.4-1.1	Si	WIDE BAND, PHOTOPIC RESPONSE
B 8"	TRANSMISSOMETER AND RADIOMETER	8" BARNES, MARK II	3.0-5.5* 8.0- 3.0	InSb/CMT	NARROW BANDS WIDE BANDS
	TRANSMISSOMETER AND SPECTRO-RADIOMETER	8" BARNES, MARK II	0.4-1.1	Si	0.4-0.7 CVF, RESOLUTION 4%* NARROW BAND WIDE BAND
	TRANSMISSOMETER*	8" EDMUND	0.4-1.1	Si	PHOTOPIC RESPONSE
C 8"	TRANSMISSOMETER*	8" AFWAL-THREE CHANNEL	0.4-1.1 2.5-14.5	Si InSb/CMT	NARROW & WIDE BAND 2.5-14.5 μm, RESOLUTION 2% WIDE BANDS

* NEW

References

1. Six Interim reports (1981-1983).
2. "SNOW ONE A - DATA REPORT", J. Butterfield and A. Ben-Shalom, ASL, W.S.M.R, NM 88002, March 1982.
3. "BATTLEFIELD INDUCED CONTAMINATION TEST - BICT-III, HIGH EXPLOSIVE DUST, DATA REPORT" J. Butterfield and A. Ben-Shalom, ASL, W.S.M.R., NM 88002, Nov. 1982.
4. "BATTLEFIELD INDUCED CONTAMINATION TEST - BICT-III, FIRE PRODUCTS, THERMAL PLUMES and FOG OIL", J. Butterfield and A. Ben-Shalom, ASL, W.S.M.R, NM 88002, Oct. 1982.
5. "SNOW ONE B - DATA REPORT", A. Ben-Shalom, R. Okrasinski, R. Olsen and J J.E. Butterfield, ASL, W.S.M.R., NM 88002, Feb. 1983.
6. "Measured spectral extinction coefficient dependence of vehicle dust at visible, IR and N.M.W.W. wavelength", R. Olsen, R. Okrasinski and A. Ben-Shalom, Infrared Phys. (1983) - see appendix B.
7. "Measured spectral extinction coefficient of rain at visible, IR and NMWW wavelength", A. Ben-Shalom (1984, submitted for publication) Infrared Phys.

ASL REPORT

SNOW ONE A

TRANSMISSION MEASUREMENTS DATA REPORT

By

Joseph Butterfield

ELECTRO-OPTICS ENVIRONMENTS BRANCH

US ARMY

ATMOSPHERIC SCIENCES LABORATORY

AND

AMI BEN-SHALOM

DEPARTMENT OF PHYSICS

TECHNION-ISRAEL INSTITUTE OF TECHNOLOGY

March 1982

ASL REPORT

LOVIR

BATTLEFIELD INDUCED CONTAMINATION TEST III (BICT III)

FIRE PRODUCTS
THERMAL PLUMES
FOG OIL

TRANSMISSION MEASUREMENTS
DATA REPORT

by

J. E. BUTTERFIELD
Measurements and Analysis Branch
US Army Atmospheric Sciences Laboratory

and

AMI BEN-SHALOM
Department of Physics
Technion-Israel Institute of Technology

OCTOBER 1982

ASL REPORT

LOVIR

BATTLEFIELD INDUCED CONTAMINATION TEST III (BICT III)

HIGH EXPLOSIVE DUST

TRASNMISSION MEASUREMENTS DATA REPORT

by

J. E. BUTTERFIELD
Measurements and Analysis Branch
US Army Atmospheric Sciences Laboratory

and

AMI BEN-SHALOM
Department of Physics
Technion-Israel Institute of Technology

NOVEMBER 1982

SNOW ONE B
VISIBLE/IR TRANSMISSION AND METEOROLOGICAL DATA REPORT

by

AMI BEN-SHALOM
Department of Physics
Technion-Israel Institute of Technology

R. OKRASINSKI
Physical Sciences Laboratory
New Mexico State University

and

R. OLSEN and J. E. BUTTERFIELD
Measurements and Analysis Branch
US Army Atmospheric Sciences Laboratory

FEBRUARY 1983

APPENDIX A

LOVIR

MOBILE LOW VISIBILITY IR

MEASUREMENTS SYSTEM .

LOVIR A.S.L

20

TECHNICAL DESCRIPTION AND SPECIFICATION OF LOVIR SYSTEM.

GENERAL: THE LOVIR SYSTEM CONSISTS OF RADIATION CHOPPED SOURCES,OPTICAL RECIEVERS AND INTERFACED DATA PROCESSING UNITS.

THE LOVIR SYSTEM IS MOBILIZED BY THE USE OF A 40 FOOT SEMI-TRAILER VAN.

IN PRINCEPLE,THE VISIBLE&I.R. SOURCE SEND CHOPPED RADIATION (1000 Hz) THROUGH THE ATMOSPHERE (UP TO 8 KM RANGE) . PART OF THIS RADIATION IS DETECTED BY SYNCHRONAUS RECIEVENING INSTRUMENTS.

THE DETECTED SIGNALS ARE SENT IN ANALOG AND DIGITAL FORMATS TO THE DATA ACQUISITION SYSTEM FOR DATA PROCESSING AND STORAGE .

RESPONSIBLE AGENCY: ATMOSPHERIC SCIENCES LABORATOTY (A.S.L.)
US ARMY ELECTRONICS R&D COMMANDS
WHITE SANDS MISSILE RANGE. NM 88002
DELAS-AS-M . (505) 678-1404
AUTOVAN 258-1404

OBJECTIVES :
* DEVELOP.IMPROVE.EXPANSE AND OPERATE A MOBILE LOW VISIBILITY IR MEASUREMENT SYSTEM (LOVIR).
* CONDUCT TESTS UTILIZING THE LOVIR SYSTEM TO MEASURE TRANSMITTANCE.CONTRAST TRANSMITTANCE AND ATMOSPHERIC RADIANCE IN THE VISIBILE AND INFRARED SPECTRUM,OF OPTICAL PATH THAT HAS BEEN DEGRADED BY NATURAL AND ARTIFICIAL CONTAMINATES.
* REDUCE,STORAGE,PROCESSE AND ANALYZE OF LOVIR MEASURED DATA.

RADIATION SOURCES:

A. SOURCE NO. 228 , MODIFY BARNES SOURCE

B. SOURCE NO. 601 , THE SAME AS SOURCE A

SOURCE A - NO. 228:

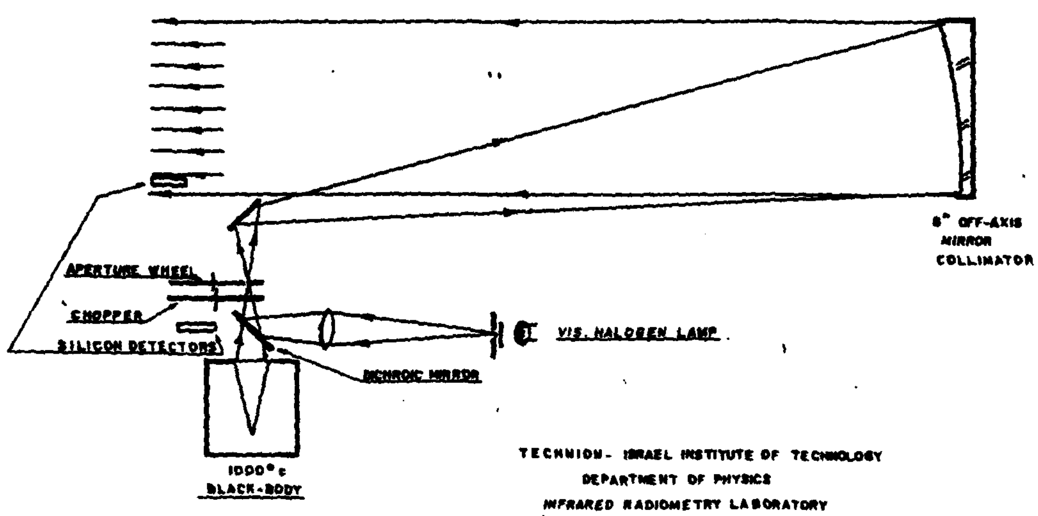
OUTPUT: VISIBLE AND INFRARED RADIATION FROM:
1. 1000 C BLACK-BODY SOURCE, WITH 1" APERTURE.
2. 3000 K TUNGSTON LAMP, 150 WATT (GE).

A BEAMSPLITTER PERMITS BOTH VISIBLE AND INFRARED RADIATION TO PASS SIMULTANEOUSLY THROUGH THE COLLIMATOR.

OPTICS: 4.8" OFF-AXIS COLLIMATOR.
MAIN MIRROR - OFF AXIS PARABOLOID
DIAMETER - 4.8 "
FOCAL LENGTH- 25.6 "
RESOLUTION - 0.2 MRAD.
ENTRANCE APERTURES - 0.0081" TO 0.256" (RATIO 1:1000 AREA)

MODULATOR: 1000 Hz FIXED SPEED MODULATOR WITH A MOTOR DRIVEN CHOPPER WHEEL.

FIG. 1



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INFRARED RADIOMETRY LABORATORY

RECIVERS
=========

SET A :

1. TRANSMISSOMETER NO. 075
   1.06 MICRON , 3.5" D QUESTAR
2. TRANSMISSOMETER NO. 076
   0.4-0.7 MICRON (PHOTOPIC), 3.5" D QUESTAR
3. TRANSMISSOMETER NO. 215
   3 - 5.5 MICRON , 4" D BARNES
4. TRANSMISSOMETER NO. 217
   8 - 13 MICRON , 4" D BARNES

SET B :

1. TRANSMISSOMETER AND RADIOMETER NO. 140
   0.4-1.1 MICRON , 8" D BARNES
2. TRANSMISSOMETER AND RADIOMETER NO. 146
   8 - 13 MICRON , 8" D BARNES
3. TRANSMISSOMETER NO. 387
   TWO COLOR : 387-1 1.06 MICRON
   387-2 0.4-0.7 MICRON
   8" D MODIFY QUESTAR

SET C :

1. TRANSMISSOMETER NO. 300
   300-1 0.4-1.1 MICRON
   300-5 3 - 5.5 MICRON
   300-10 8 - 13 MICRON
   AFWAL THREE COLOR, 8" D .

SET D :

1. RADIOMETER NO. 475
   9.5-11.5 MICRON, PRT-5 BARNES
2. RADIOMETER NO. 501
   9.5-11.5 MICRON, PRT-5 BARNES

RECIVER 075
============

OPTICAL SYSTEM - CASSEGRAIN
ENTRANCE APERTURE- 3.5" DIA.
FIELD OF VIEW - 24 MRAD.
FOCAL LENGTH - 20 "

DETECTOR TYPE - SILICON
DETECTOR NO. SD-100-42-12-231

FILTER - 1.06 MICRON (HBW=0.01 MICRON)

RECIVER 076
============

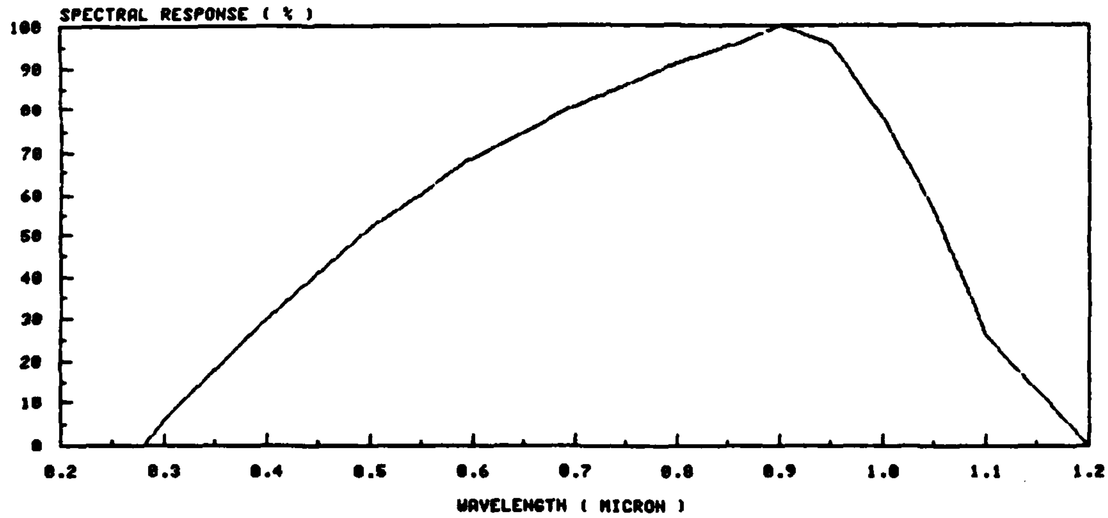
OPTICAL SYSTEM - CASSEGRAIN
ENTRANCE APERTURE- 3.5" DIA.
FIELD OF VIEW - 24 MRAD.
FOCAL LENGTH - 20 "

DETECTOR TYPE - SILICON
DETECTOR NO. SD-100-42-12-231

FILTER - 0.4-0.7 MICRON (PHOTOPIC RESPONSE)

SILICON DETECTOR SD-100-42-12-231

0.4-1.1 MICRON



RECIVER NO. 215
==================

OPTICAL SYSTEM - CASSEGRAIN
ENTRANCE APERTURE- 4.25"
FIELD OF VIEW - 2.5 MRAD.
FOCAL RANGE - 3' TO INFINITY
SIGHTING - ON AXIS

DETECTOR NO. 215-517 ,
TYPE - InSb , 77 K (LN2).
N.E.T. =0.00037 K (1Hz,1000Hz,25C)

FILTERS - W.B. OR N.B. DISCRETE FILTERS.

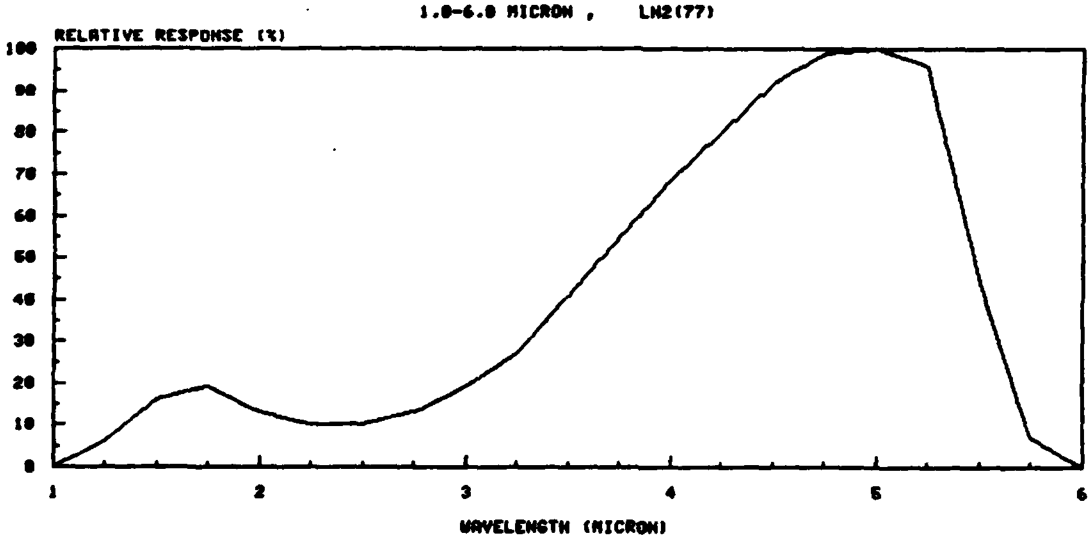
* SPECTRAL RESPONSE PLOTS FOR DETECTORS AND FILTERS ARE PRESENTED WITH LOW RESOLUTION ONLY. HIGH RESOLUTION INFORMATION AVIALABLE UPON REQUEST.

THIS RECIVER OPERATES IN TRANSMISSOMETER MODE ONLY!

S/N > FOR W.B. FILTER } 1KM RANGE
S/N > FOR N.B. FILTER

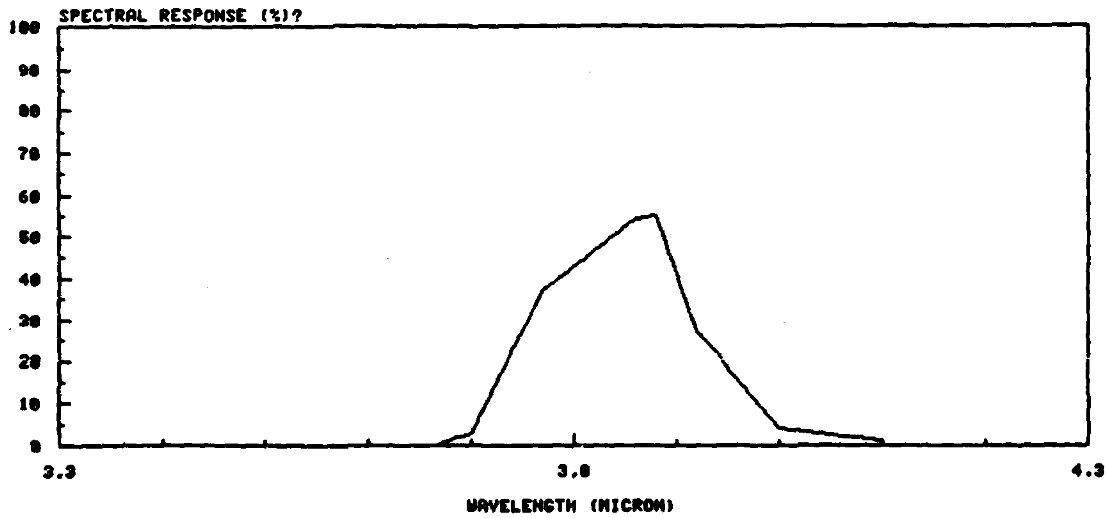
InSb DETECTOR No. 215- 517

1.0-6.0 MICRON , LN2(77)



FILTER NO. 215 - 30 , N.B.

3.8 MICRON, HBW=0.1 MICRON



RECIVER NO. 217
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OPTICAL SYSTEM - CASSEGRAIN
ENTRANCE APERTURE- 4.25"
FIELD OF VIEW - 2.79 MRAD.
FOCAL RANGE - 3' TO INFINITY
SIGHTING - ON AXIS

DETECTOR NO. 217-657 ,
TYPE - HgCdTe , 77 K (LN2).
$D^{*} = 1.95\ 10^{10}\ CM(Hz)^{1/2}$/WATT AT (PK.,1Hz,1000Hz)

FILTERS - W.B. OR N.B. DISCRETE FILTERS.

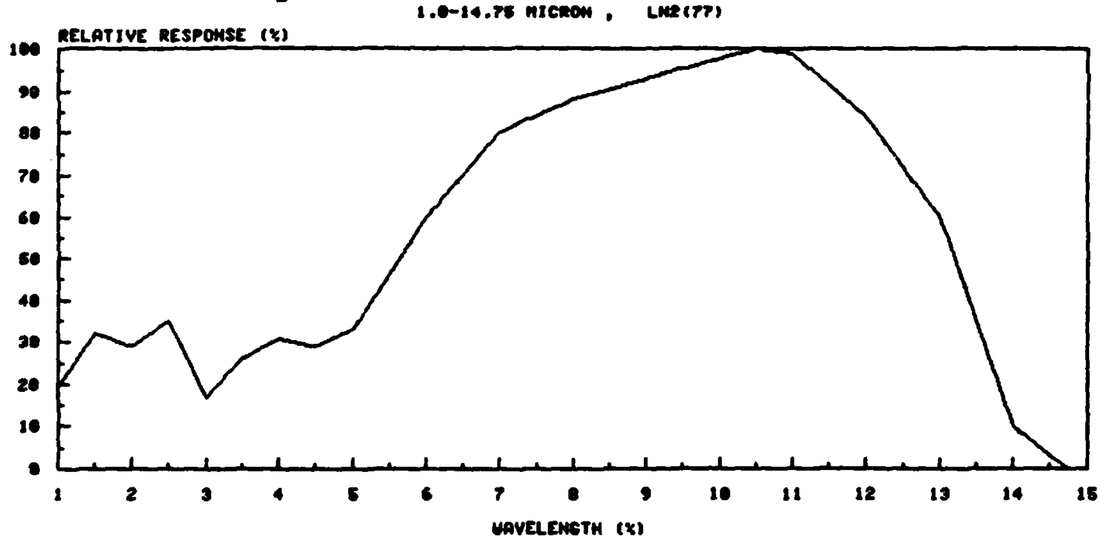
* SPECTRAL RESPONSE PLOTS FOR DETECTORS AND FILTERS
ARE PRESENTED WITH LOW RESOLUTION ONLY. HIGH RESOLUTION
INFORMATION AVIALABLE UPON REQUEST.

THIS RECIVER OPERATES IN TRANSMISSOMETER MODE ONLY!

S/N > FOR W.B. FILTER] 1KM RANGE
S/N > FOR N.B. FILTER

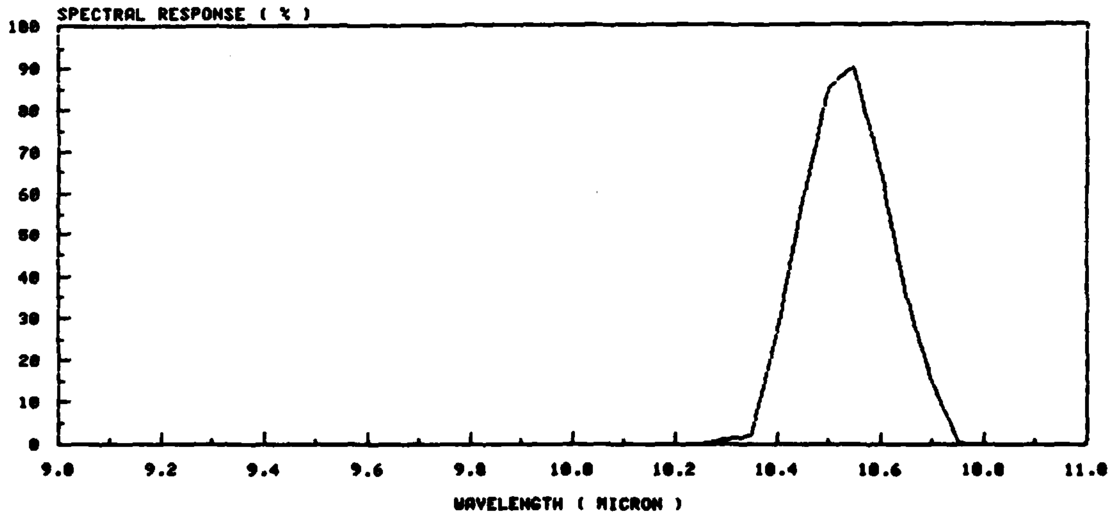
HgCdTe DETECTOR No.217-657

1.0-14.75 MICRON , LN2(77)



FILTER NO. 217-05 , N.B.

10.6 MICRON , HBW=0.2 MICRON



RECIVER NO. 300

AFWAL THREE COLOR SYSTEM

OPTICAL SYSTEM - OFF AXIS PARABOLIC MIRROR

ENTRANCE APERTURE - 8" DIA.

FOCAL LENGTH - 25 " .

CHANNEL 300-1

SPECTRAL WINDOW - 0.4-1.1 MICRON

FIELD OF VIEW - 5 MRAD.

DETECTOR TYPE - SILICON

DETECTOR NO. - SD-100-42-12-231

CHANNEL 300-5

SPECTRAL WINDOW - 2 - 5.6 MICRON

FIELD OF VIEW - 2 MRAD.

DETECTOR TYPE - INSB , 77K (LN2)

$D^{*}=2\ 10^{11}$ $CM(HZ)^{1/2}$ /WATT (PK, 1HZ,1KHZ)

DETECTOR NO. F-1115R

CHANNEL 300-10

SPECTRAL WINDOW - 6 - 14 MICRON

FIELD OF VIEW - 2 MRAD.

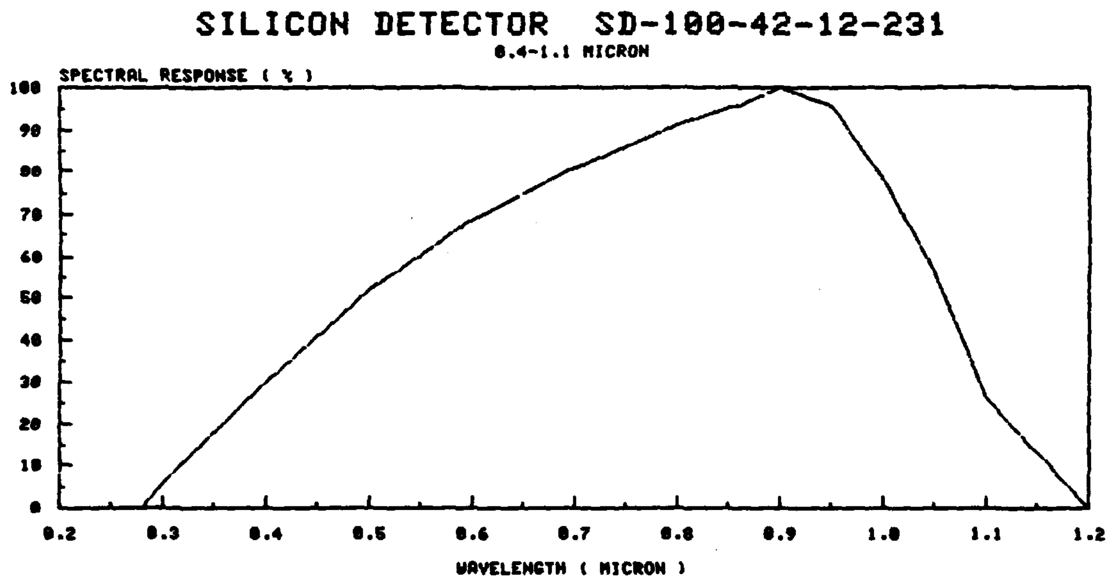
DETECTOR TYPE - HgTeCd , 77K (LN2)

$D^{*} = 1\ 10^{10}$ $CM(HZ)^{1/2}$ /WATT (PK, 1HZ,1KHZ)

DETECTOR NO. F-1115R

FILTERS - W.B. OR N.B.

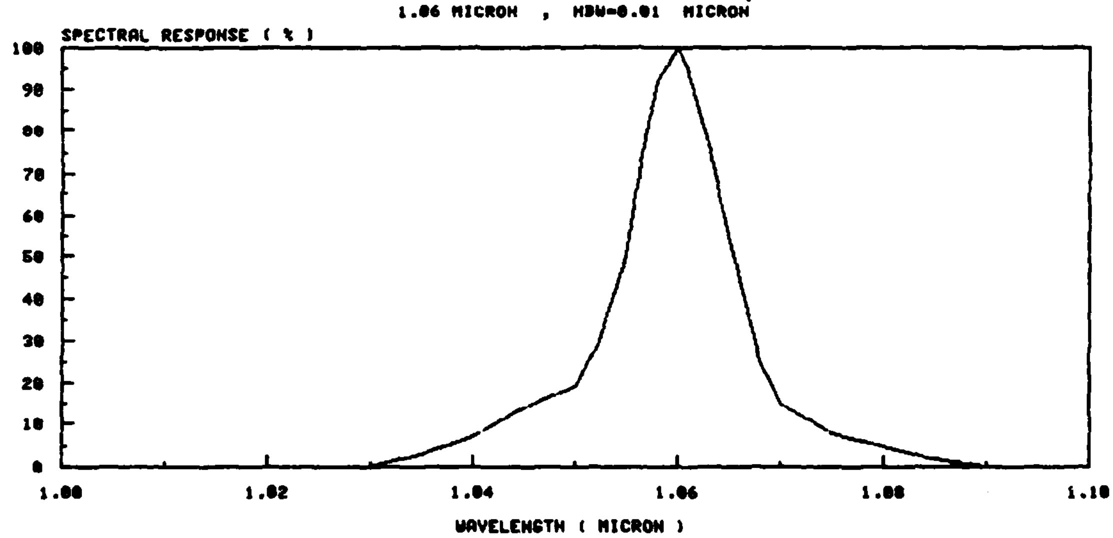
THIS RECIVER OPERATES IN TRANSMISSOMETER MODE ONLE!

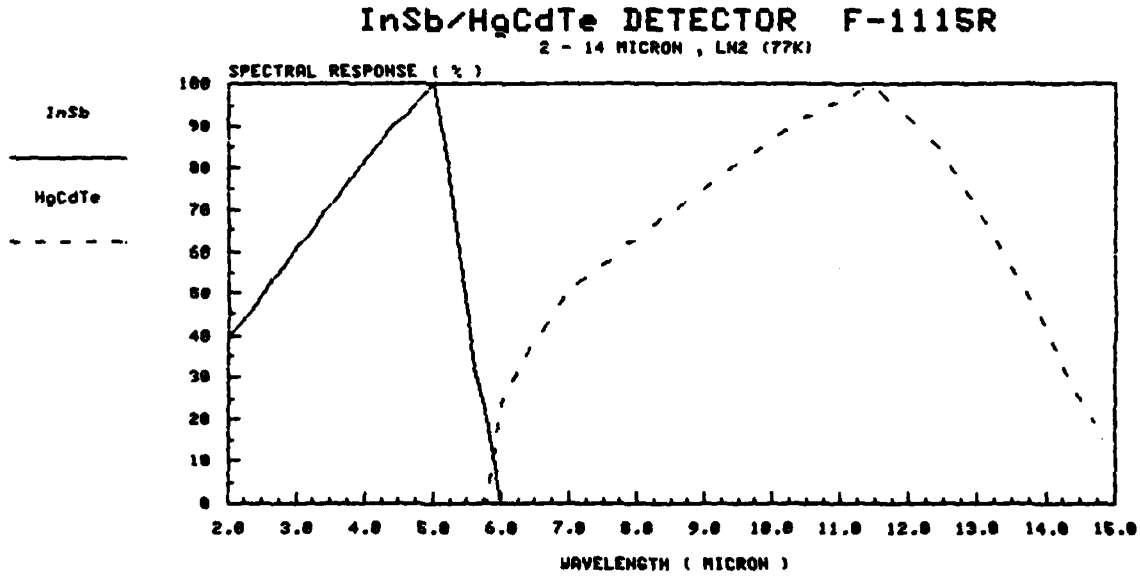


SILICON DETECTOR SD-100-42-12-231
0.4-1.1 MICRON
SPECTRAL RESPONSE (%)
100
90
80
70
60
50
40
30
20
10
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
WAVELENGTH (MICRON)

1.06 MICRON FILTER , N.B.

1.06 MICRON , HBW=0.01 MICRON





InSb/HgCdTe DETECTOR F-1115R
2 - 14 MICRON , LN2 (77K)
SPECTRAL RESPONSE (%)
InSb
HgCdTe
100
90
80
70
60
50
40
30
20
10
0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
WAVELENGTH (MICRON)

APPENDIX B

PAPER REPRINT

MEASURED SPECTRAL EXTINCTION COEFFICIENT
DEPENDENCE OF VEHICLE DUST AT VISIBLE,
IR AND NMMW WAVELENGTH

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ABSTRACT

Measurements were made at visible, infrared (IR), and near millimeter wave (NMMW) wavelengths to determine the effect of vehicle generated dust clouds on transmission. Results from these tests indicated little or no attenuation at NMMW frequencies (96 Ghz, 140 Ghz, 220 Ghz), while there were appreciable transmittance loss at visible (0.4-1.1 μm) and IR (3.0-5.5 μm, 8.0-13.0 μm) wavelengths. Analysis of the visible and IR transmittance data indicated a spectral dependancy occurred after the fallout of the heavier particles and the dust cloud became stabilized. Extinction coefficients were calculated for each of the bandwidths. The ratio between the IR, NMMW, and visible wavelengths were 0.86 for 3.0-5.5 μm, 0.78 for 8-13 μm, and less than 10^{-3} for 96 GHz, 140 GHz, and 220 GHz.

INTRODUCTION

The ability to quantify the effects of dust on electro-optical devices requires validated models and knowledge of sensor performance. The Atmospheric Sciences Laboratory (ASL) has developed a comprehensive model entitled "Electro-Optical Systems Atmospheric Effects Library-1982 (EOSAEL 82)" (Ref 1). One of the subprograms of the EOSAEL-82 program predicts the transmission or obscuration due to dust clouds generated by vehicles, based on the type of dust, vehicle size, weight, velocity and atmospheric conditions.

A field measurement program was set up at Ft. Belvoir during Jul 82 to measure the attenuation of NMMW, visible, and IR transmission through dust clouds. The tests were limited in scope, utilizing one type of vehicle, a 3/4 ton stake bed truck driven at different speeds over the same roadway. No attempt

was made to sample the dust clouds, other than to measure transmittance through the cloud. Results from the test were to be used for a transmission data base and EOSAEL-82 model validation.

INSTRUMENTATION

The ASL transmissometer system consisted of a three color receiver, a visible and black body source and a data acquisition system. The design of the three color receiver was based on an off-axis 8-inch parabolic mirror and a 25-inch focal length for collecting the visible and infrared source radiation. Radiation is spectrally split by a dichromic mirror, which reflects the visible radiation to a Si detector and IR radiation to a InSb/MgCdTe two color watered detector (Figure 1). Each channel has an appropriate filter, visible, IR, narrow or wide band, positioned in front of the detector. The receiver simultaneously detects three signals (visible, 3-5.5, 8-13 μm), phase locks them with the source chopper frequency, determines its magnitude and provided three analog voltage outputs to the data acquisition system, where the output voltages are digitized, formatted and stored on magnetic tape.

The receiver was set up in a van, with the data acquisition unit and transmissometer controls. The path length between source and receiver was 983 meters. Both receiver and source were set at a height of 2 meters above the ground surface. The source consisted of a 3000^{0} visible light source, a $1000^{0}C$ black body, a 4.7-inch colliminator, and a 1000 Hz mechanical chopper. For the vehicle dust tests the transmissometers were operated in the following wide band modes; 0.4-1.1 μm (visible), 3.0-5.5 μm, 8.0-13.0 μm. The data was collected

simultaneously at the rate of one sample per second for each of the trials. NMMW measurements were made by the Harry Diamond Laboratories

Mobile Measurement Facility (Ref 3). The line of sight for the NMMW and ASL transmissometers paralleled each other with a path offset of 4 meters. This setup resulted in all wavelengths sampling approximately the same path. The NMMW frequencies were 96 GHz, 140 GHz, and 220 GHz.

EXPERIMENTAL DATA

The dust trials were conducted using a 3/4 ton stake bed truck which was run up and down a roadway at various specified speeds. To increase the amount of dust raised by the vehicle, a cargo pallet was attached to the truck bumper and dragged behind the vehicle. The roadway ran parallel to the line-of-sight and, with the aid of crosswinds, the dust clouds carried across the transmission line-of-sight.

The data was reduced in terms of 100% transmission for clear air with the data normalized to the clear air reference. This was done by maximizing the signals during the clear air phase before and after completion of all the trials. The system error for transmittance in the various bandwidths was:

0.4 μm-1.1 μm	0.5%
3.0 μm-5.5 μm	0.5%
8-13 μm	1.0%

Variations due to gaseous and aerosol effects are removed by normalizing the signals before and after the trials. A zero reference signal was obtained by blocking the source signal to the receiver.

Table 1 lists the various trials and meteorological conditions. Individual plots of transmittances for three speeds, 25 mph, 35 mph, and 45 mph are shown in Figures 2-4. As can be seen in these plots, visible and IR wavelengths experienced large changes in transmittance, while there was very little attenuation through the dust cloud at NMMW frequencies, as indicated by the 1.0 transmittance level for NMMW. Though both the visible and IR indicated large variations in transmittance, there appeared to be differences which were wavelength dependent. A closer analysis was made of differences by calculating the extinction coefficient for all wavelengths.

EXTINCTION COEFFICIENT

The transmittance data from the vehicle dust trials were used to calculate the effective relative extinction coefficient versus time by the following equation:

$$\beta_{eff}\{\Delta\lambda\} = -\ln\tau_m\{\Delta\lambda\} = L\alpha_m\{\Delta\lambda\} \qquad (1)$$

where m is measured, $\beta_{eff}\ \{\Delta\lambda\}$ is the effective extinction for the wavelength bandwidth $\{\Delta\lambda\}$, $\alpha_m\ \{\Delta\lambda\}$ is the measured extinction coefficient for the wavelength bandwidth $\{\Delta\lambda\}$ and L is the transmittance path length of 893 meters. Equation 1 yields:

$$\frac{\beta_{eff}(IR)}{\beta_{eff}(VIS)} = \frac{\alpha_m(IR)}{\alpha_m(VIS)} \qquad (2)$$

The ratios between the visible and each of the IR bandwidths were calculated for each of the trials and examined as a function of time. An example of this analysis is shown in Figure 5.

At time T_s the dust cloud enters the line-of-sight, at time T_a a wavelength dependence between the visible and IR begins to appear. This is due to the larger particles falling out of the dust cloud. In the time interval between T_s and T_a there is no wavelength difference in IR and visible transmittance, ΔTm is used to denote this period. At T_B all the large particles have fallen out of the cloud and it is in a stable condition. At T_p the dust moves out of the line-of-sight. The following expression is derived:

$$\Delta T_s = T_p - T_B \tag{3}$$

which defines the period of time when the cloud is in a stable condition and there is no change in the size distributions of the dust particles. During this period, values for the extinction coefficient as a function of wavelength can be obtained by determining the ratio between IR and visible wavelengths. Figure 6 is an example of these calculations and shows the time sequence and spectral dependence between the IR and visible as a ratio of the calculated extinction coefficients. Figure 7 is a scatter plot of the data shown in the previous figure indicating the relationship between visible and IR (3-5.5 μm) extinctions. The line through the data points represents a linear least squares regression. The scatter for these are small in the ΔT_s time period, with a typical correlation coefficient of 0.9 or better. The results of analyzing all of the trials are listed in Table 1. The only parameter to vary with vehicle velocity was ΔT_m.

which indicated an increase with increased vehicle velocity. Calculations of the extinction coefficients ratios for the various wavelengths are listed in Table 2. These values indicate a spectral dependency for IR and NMMW wavelengths in stabilized dust clouds.

CONCLUSIONS

The analysis of visible, IR, and NMMW transmission through dust clouds generated by a vehicle indicates a spectral dependency which varies as a function of time. The NMMW was not attenuated by the dust cloud and no loss of transmittance was seen at 94 GHz, 140 GHz, and 220 GHz. Initially, when the dust cloud crossed the IR and visible line-of-sight, there was an appreciable decrese in transmission which was the same both for the IR and visible wavelengths. After the initial period, the large particles began to fall out and differences began to appear between the IR and visible. Once all the larger particles had fallen out of cloud and the cloud became stabilized, the differences between the frequencies became apparent. The ratio of averaged extinction coefficients compared to the visible were .86 for 3-5.5 μm, .78 for 8-13 μm, and $>10^{-3}$ for NMMW wavelengths. These results indicate the scattering effects of IR, as the wavelengths approach the visible bandwidth.

Results from these trials, though limited, indicate that a spectral difference in a stabilized dust cloud does occur. Further tests should be conducted at other locations with different soils to determine if this type of phenomena persists, with the objective of incorporating the results into the EOSAEL model.

REFERENCES

1. L. D. Duncan, R. C. Shirkey, and M. B. Richardson, "EOSAEL 82-Transmission Through Battlefield Aerosols," ASL-TR-0122, Vol. II, Nov 82, US Army Atmopsheric Sciences Laboratory, White Sands Missile Range, NM 88002.

2. R. R. Gruenzel, W. C. Martin, and M. J. Schumerk, "Design and Implementation of a Broadband Infrared Atmospheric Transmissometer," SPIE Proceedings, Vol. 277, p. 168 (Apr 81).

3. R. W. McMillan, R. G. Shackelform and J. J. Gallagher, "Millimeter Wave Beamrider and Radar Systems," SPIE Proceedings, Vol. 259, p. 166 (Oct 80).

FIGURES

TABLES

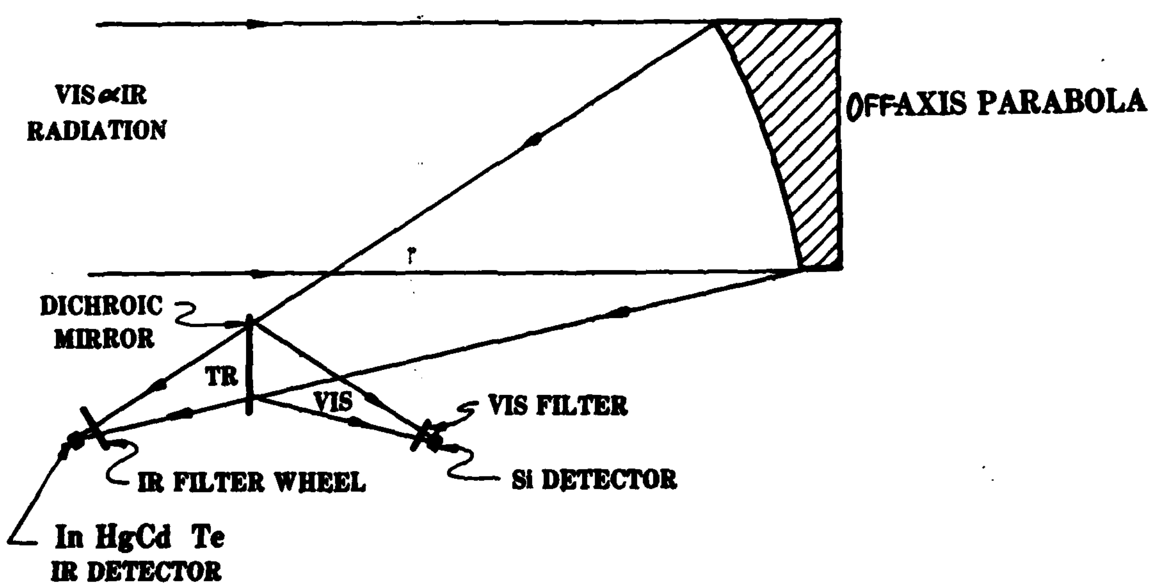
TABLE 1

TRIAL NO.	VEHICLE SPEED MPH	$\frac{\alpha 3\text{-}5.5}{\alpha VIS}$ MEAN	(STD)	$\frac{\alpha 8\text{-}13}{\alpha VIS}$ MEAN	(STD)	METEOROLOGICAL DATA
1	35	0.840	(0.028)	0.781	(0.043)	
2	35	0.858	(0.021)	0.771	(0.029)	Wind Speed 3.1 MPH
3	25	0.862	(0.020)	0.792	(0.036)	Wind Direction 182
4	25	0.897	(0.026)	0.828	(0.043)	
5	35	0.855	(0.028)	0.774	(0.028)	Air Temperature 23^{o}
6	35	0.844	(0.028)	0.717	(0.045)	Relative Humidity 75
7	45	0.873	(0.038)	0.784	(0.062)	
8	45	0.818	(0.015)	0.742	(0.030)	Visibility >25 μm

VEHICLE CLOUD DUST RELATIVE EXTINCTION COEFFICIENTS

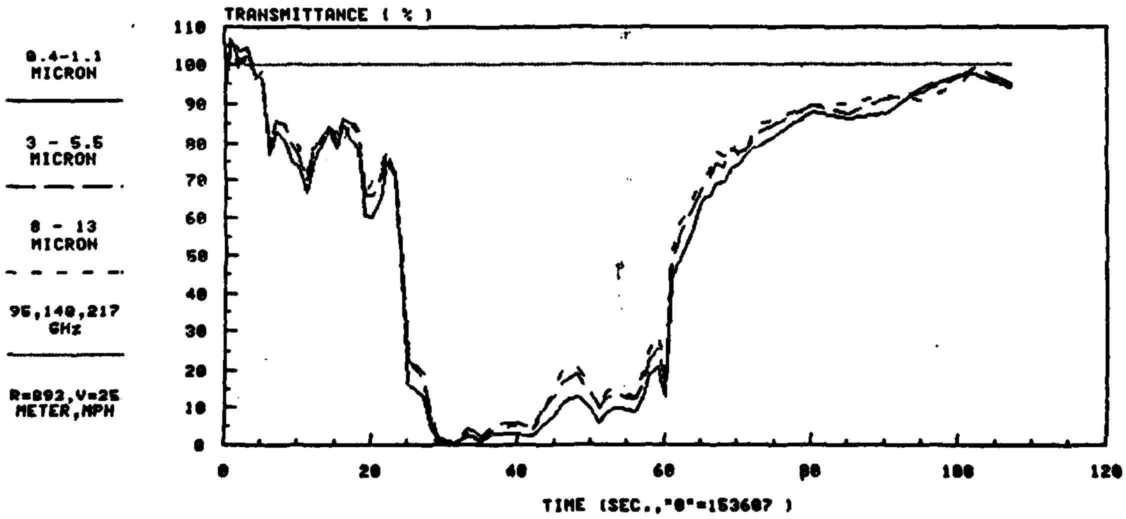
α_i/α_{VIS}	i # 0.4-1.1μm	i # 3-5.5 μm	i # 8-13 μm	i # 95, 140, 220 GHz
SOIL Ft. Belvoir	1.00	0.86	0.78	$<10^{-3}$

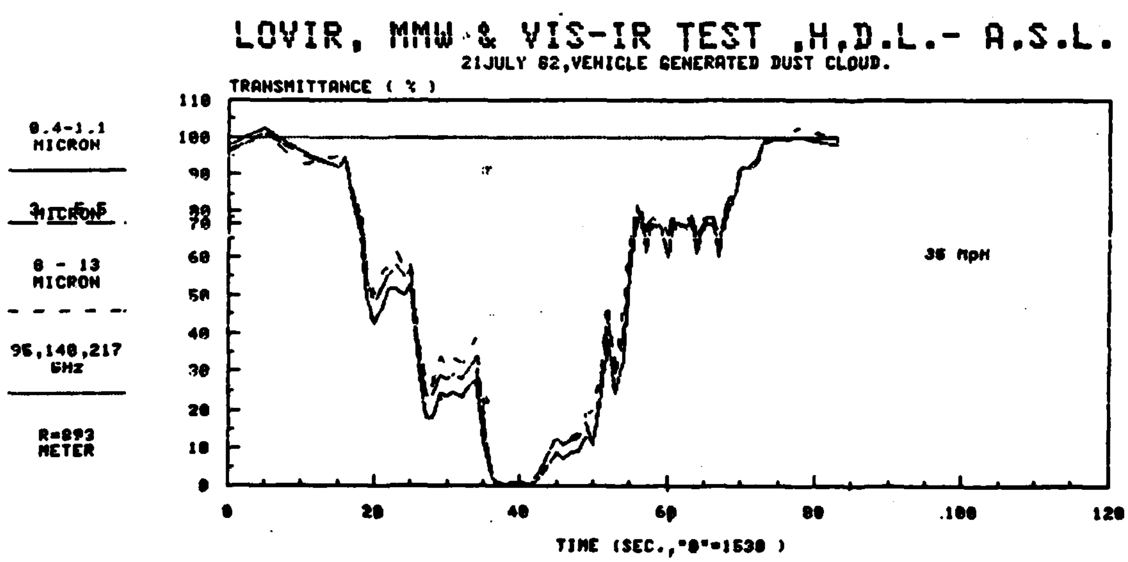
ASL THREE COLOR RECEIVER, OPTICAL LAYOUT



LOVIR, MMW & VIS-IR TEST ,H.D.L.- A.S.L.

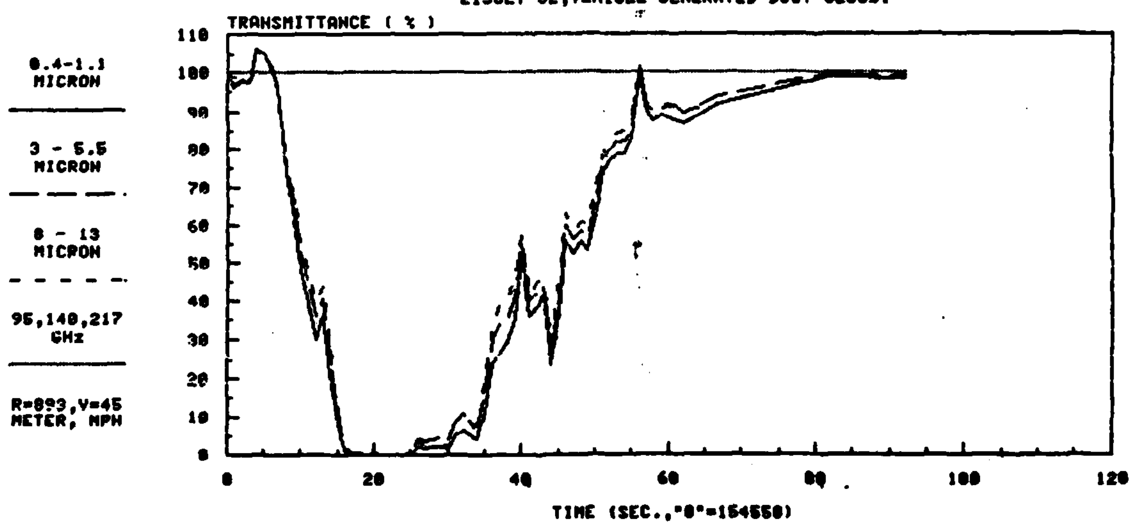
21JULY 82,VEHICLE GENERATED DUST CLOUD.

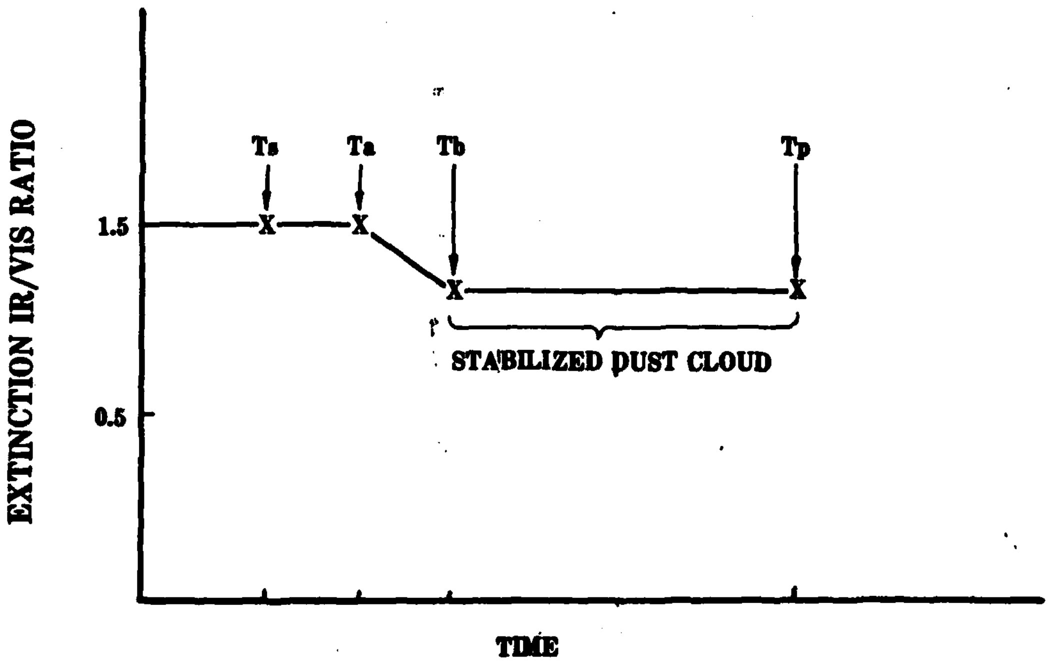


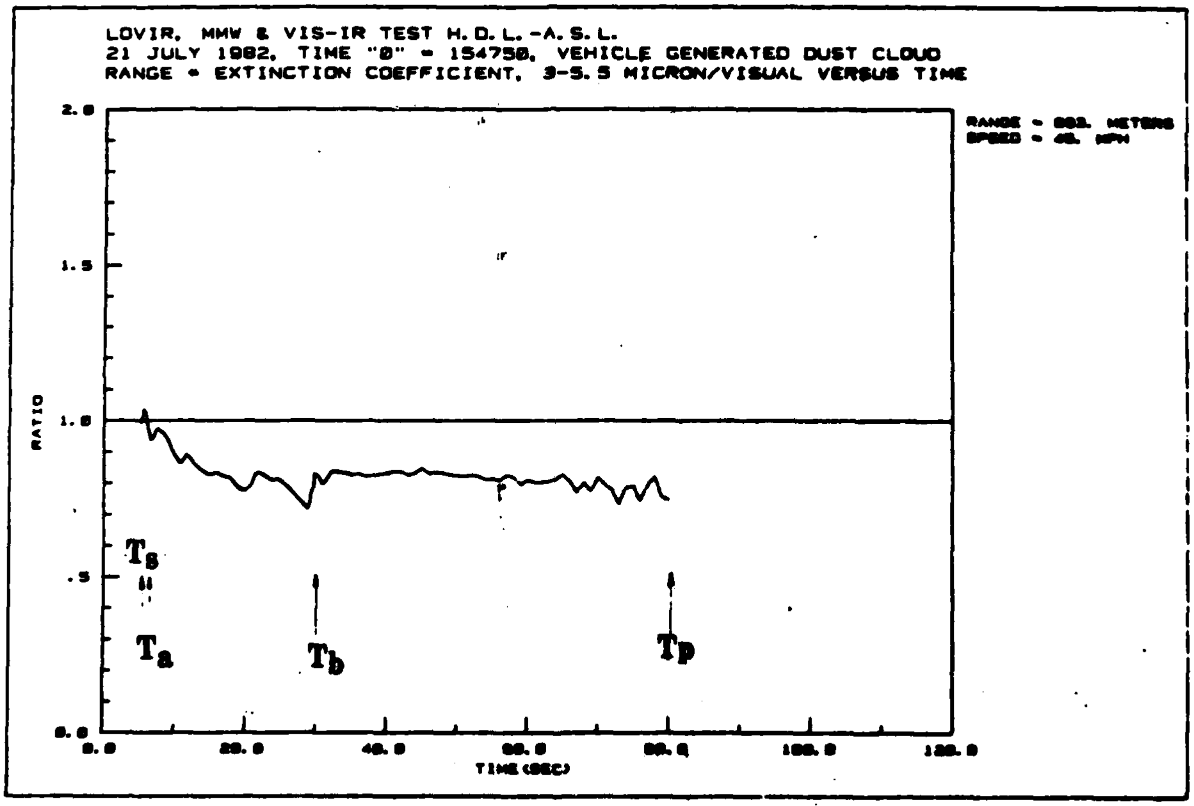

LOVIR, MMW & VIS-IR TEST ,H.D.L.- A.S.L.
21JULY 82,VEHICLE GENERATED DUST CLOUD.
TRANSMITTANCE (%)
0.4-1.1 MICRON
3 - 5.5 MICRON
8 - 13 MICRON
96,140,217 GHz
R=893 METER
36 MPH
TIME (SEC.,"0"=1530)

LOVIR, MMW & VIS-IR TEST ,H.D.L.- A.S.L.

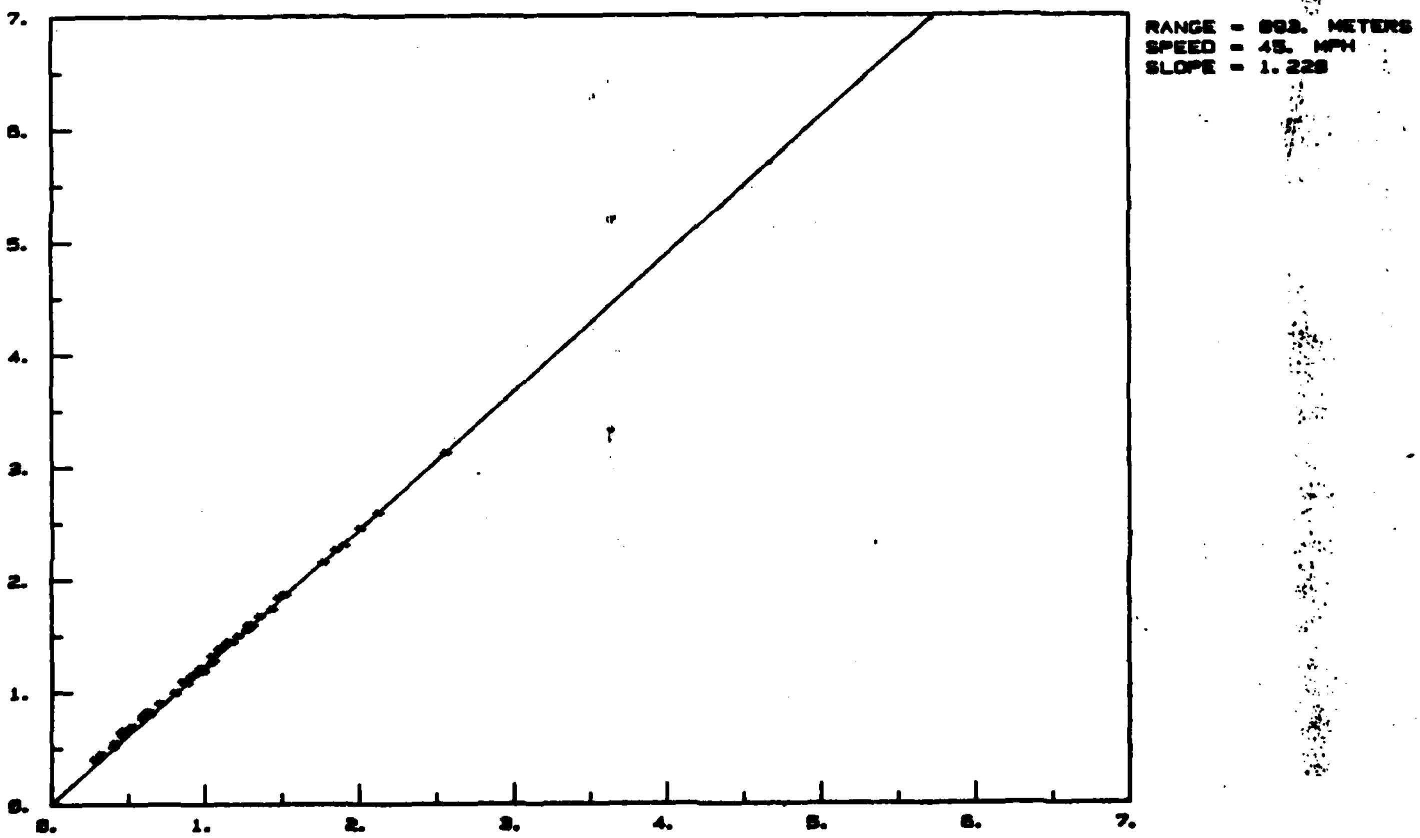
21JULY 82,VEHICLE GENERATED DUST CLOUD.




Ts
Ta
Tb
Tp
1.5
0.5
X
STABILIZED DUST CLOUD
EXTINCTION IR/VIS RATIO
TIME


LOVIR, MMW & VIS-IR TEST H.D.L.-A.S.L.
21 JULY 1982, TIME "0" = 154750, VEHICLE GENERATED DUST CLOUD
RANGE = EXTINCTION COEFFICIENT, 3-5.5 MICRON/VISUAL VERSUS TIME
RANGE
SPEED
METERS
MPH
RATIO
2.0
1.5
1.0
.5
0.0
20.0
40.0
60.0
80.0
100.0
120.0
TIME (SEC)
T_s
T_a
T_b
T_p

LOVIR, MMW & VIS-IR TEST H. D. L. -A. S. L.
21 JULY 1982, TIME "Ø" = 154750, VEHICLE GENERATED DUST CLOUD
RANGE * EXTINCTION COEFFICIENT, VISUAL VERSUS 3-5.5 MICRON



Optical properties of vehicular dust cloud in the visible, infrared and near milimeter wavelength.

by

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and

R. OLSEN

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White Sands Missile Range, New Mexico.

Man made aerosols in the atmosphere generated by moving vehicles or detonation of artillery munitions may affect Electro-Optical devices operated in the visible, infrared and near milimeter wavelengths.

The determination of the optical properties of dust cloud can be approached from first principle if the refractive index, the particle size/number distribution and the shape of the dust grains are known. Specifically, Mie theory modified for nonspherical particles could be used to calculate the extinction, scattering and absorption coeffcients as a function of wavelength.

Dust particle size measurements presented in Ref.1,2 show that all dust size distributions, irrespective of soil or generating source type exhibit a bimodel character with mass mean radii of 5 and 70 micron. Using these data with modified Mie theory allows us to calculate the predicted extinction coefficients for the visible and infrared region.

These predictions suggest that extinction should be neutral (wavelengt independet) for the airborne dust clouds, after the ballistic trajecto large particles (>200 micron) have settled to the ground.

A field measurement program was set up at Ft. Belvoir, VA. during June 1982 to measure the attenuation of visible, infrared and near milimeter wavelength through vihicular dust clouds. The tests were limited in scope, utilizing one type of vehicle on one type of soil, driven at different speeds over the same roadway. No attempt was made to sample the dust clouds, other than to measure spectral transmittance through the dust cloud for model validation.

The instrumentation used for these measurements is described in some detail in Ref.3,4. For the purpose of this Letter, it is sufficient to remark that spectral transmittance measurements are made at 0.4-0.7, 3 -5.5, 8 -13 micron and 95, 140, 220 GHz. Variations due to gaseous and aerosol effects are removed by normalizing the clear air signals before and after trials. Visible and infrared measurements were made by the Atmospheric Sciences Laboratory and the near milimeter measurements were made by the Harry Diamond Laboratorie's. The horizontal line of sight for the transmissometers was 893 meters, about 2 meter above ground.

In Fig.1,2 we show selected samples of transmittance data through vihicular dust cloud. These plots are typical of the results of all our tests, showing a increase in transmittance with increased wavelength. In the near milimeter wavelengths, no attanuation or loss of transmittance by the dust cloud was seen.
All transmittance data were reduce to calculated effective extinction coefficients by:

$$\alpha_m(\Delta\lambda) = \frac{-\ln \tau_m(\Delta\lambda)}{L} \qquad (1)$$

where $\alpha_m(\Delta\lambda)$ is the effective extinction coefficient for wavelength band $\Delta\lambda$, and L is the path length. The extinctin coefficient ratio between the visible (VIS) and each of the infrared (IR) band are calculated by :

$$\frac{\alpha_m(IR)}{\alpha_m(VIS)} = \frac{\ln \tau_m(IR)}{\ln \tau_m(VIS)} \qquad (2)$$

Fig.3 present a histogram of this ratio for the 3 - 5.5 micron IR band, and it is clear from it that short time after the dust cloud enters the line of sight, a constand ratio between the visible and infrared begins to appear. This is due to the larger ballistic particles falling out of the dust cloud and the cloud has a bimodal character of size distribution.
Fig.4 is scatter plot, showing the relationship between the visible and infrared extinction data. The line through the data is from a linear least sgueres regression with a typical correlation coefficient of 0.9 or better. Coefficients ratios for the various wavelengths are presented in Table 1, and indicates a weak wavelength dependence in the visible and infrared region.

These results indicate that the residual weak wavelength dependence is prpbably due to multiple scattering, which has not been include in the models.

References:

1. R.G. Pinnick, G. Fernandez and B.D. Hinds, Appl. Opt. 22, 95(1983).
2. R.G. Pinnick, Atmospheric Sciences Laboratory; private communication (1983).
3. R.R. Gruenzel, W.C. Martin and M.J. Schuwerk, SPIE PROC. 277, 168 (1981).
4. R.W. McMillan, R.G. Shackelford and J.J. Gallagher, SPIE PROC.259, 166 (1980).

Tables:

1. Vehicle cloud dust relative extinction coefficients.

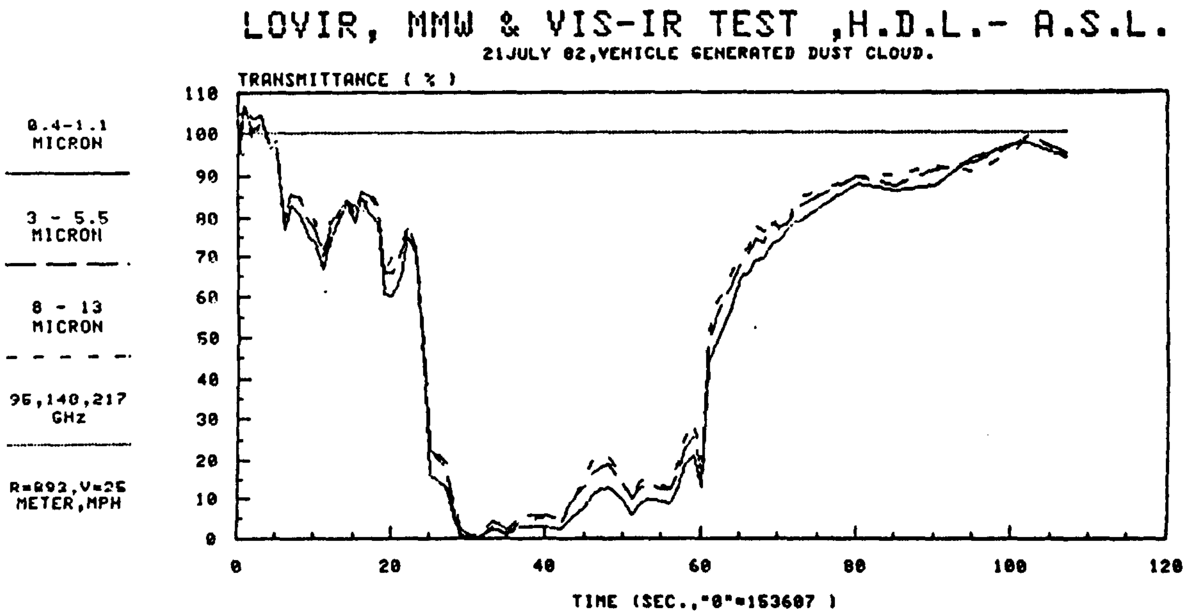
Figures:

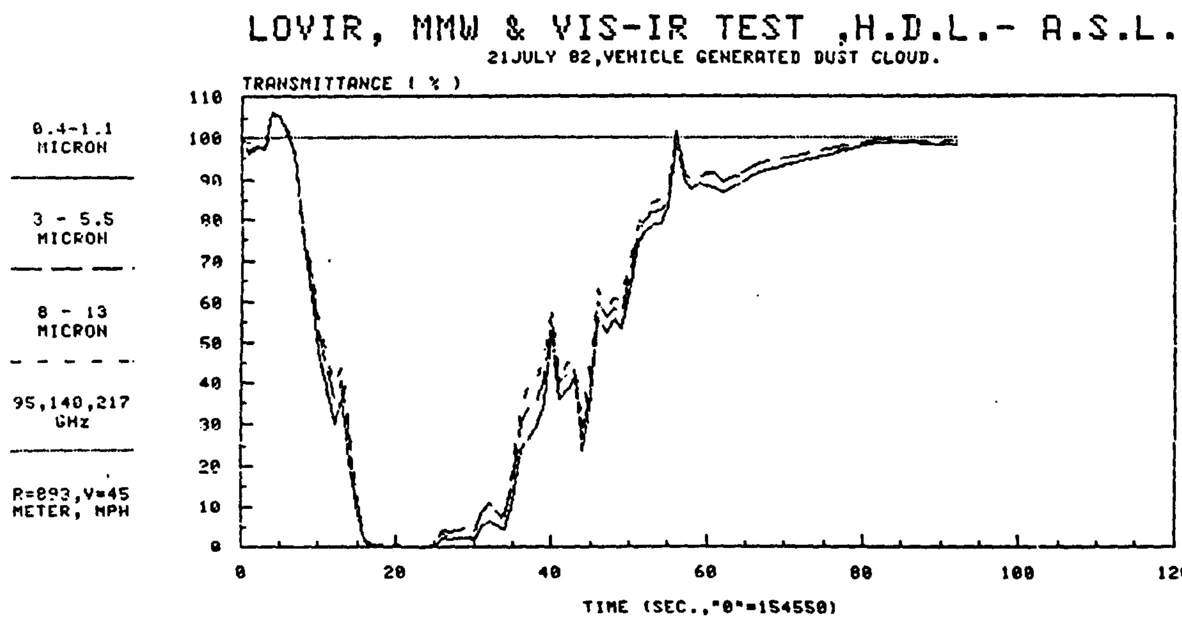
1. Visible, IR and NMMW transmittance through vehicular dust cloud, at 25 mph.

2. Visible, IR and NMMW transmittance through vehicular dust cloud, at 45 mph.

3. IR(3-5.5μm) to visible extinction coefficient ratio as a function of time.

4. Scatter plot of visible to 3-5.5μm extinction coefficients data points in a stabilized dust cloud.

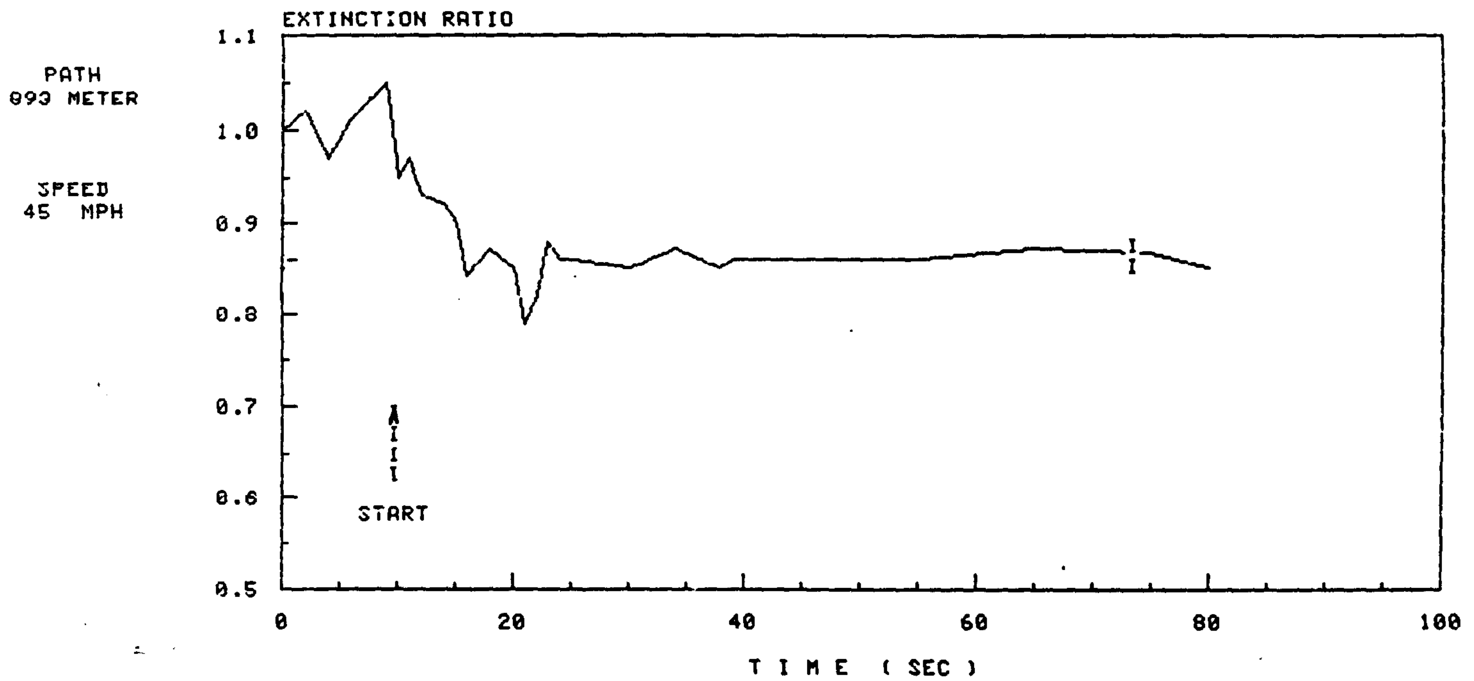

LOVIR, MMW & VIS-IR TEST ,H.D.L.- A.S.L.
21JULY 82,VEHICLE GENERATED DUST CLOUD.
TRANSMITTANCE (%)
0.4-1.1 MICRON
3 - 5.5 MICRON
8 - 13 MICRON
95,140,217 GHz
R=892,V=25 METER,MPH
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
TIME (SEC.,"0"=153607)



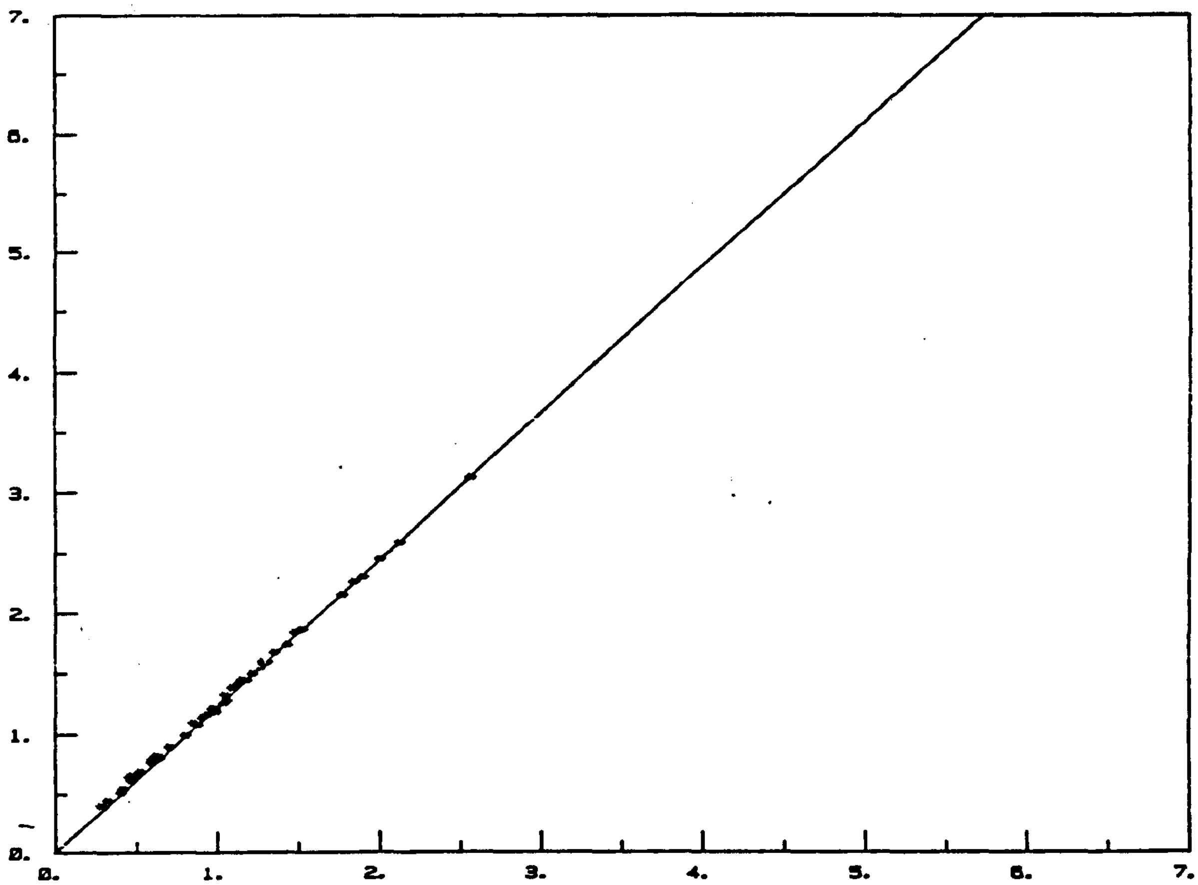
LOVIR, MMW & VIS-IR TEST ,H.D.L.- A.S.L.
21JULY 82,VEHICLE GENERATED DUST CLOUD.
TRANSMITTANCE (%)
0.4-1.1 MICRON
3 - 5.5 MICRON
8 - 13 MICRON
95,140,217 GHz
R=893,V=45 METER, MPH
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
TIME (SEC.,"0"=154550)

VEHICLE GENERATED DUST CLOUD - IR/VIS

21 JULY 1982, 3-5.5/VIS RATIO VR TIME



21 JULY 1982, TIME "Ø" = 154750, VEHICLE GENERATED DUST CLOUD
RANGE * EXTINCTION COEFFICIENT, VISUAL VERSUS 3-5.5 MICRON



RANGE = 893. METERS
SPEED = 45. MPH
SLOPE = 1.220

TABLE NO. 1

Vehicle cloud dust relative extinction coefficients.

α_i/α_{vis}	VIS $i=0.4-1.1\,\mu m$	IR $i=3-5.5\,\mu m$	IR $i=8-13\,\mu m$	NMMW $i=95,140,220$ GHz
SOIL Ft. Belvoir	1.00	0.86	0.78	$< 10^{-3}$